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Fast Switches Formed by a Low Temperature Direct Ink Writing Process

J. W. Tringe, C. Zhu, C. M. May, H. W. Levie, E. B. Duoss, D. M. King, A. W. Weimer

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Fast switches formed by a low temperature direct ink writing process

Joe Tringe, Cheng Zhu, Chadd May, Harold Levie, Eric Duoss, David King and Al Weimer

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We demonstrate a fast switches formed by a low temperature direct ink writing process that is compatible with thin, flexible polymer substrates. The switching material is a polymer composite with metallic particles; the particles are coated by atomic layer deposition with a thin insulating layer. The voltage switching threshold can be controlled by the particle size, the type of the insulating coating as well as its thickness, and also by the length of the switching path between two electrodes.

For these experiments, the switching particles were 10-14 micron diameter aluminum particles with 25 angstroms of aluminum oxide on the surface. For direct ink writing, the particles were mixed in a silicone matrix to create a viscous liquid. Conductive paths in the circuit were formed with a silver particle-based epoxy, and a resistor was created with a carbon-based ink (VRI-1K, from Conductive Compounds, Inc.). The substrate is 25 micron thick Kapton on a copper backing foil. To cure the epoxy and polymer matrices, the circuit and substrate was annealed in air at 200 C for ten minutes after writing. A photograph of a typical switch is shown in Figure 1.

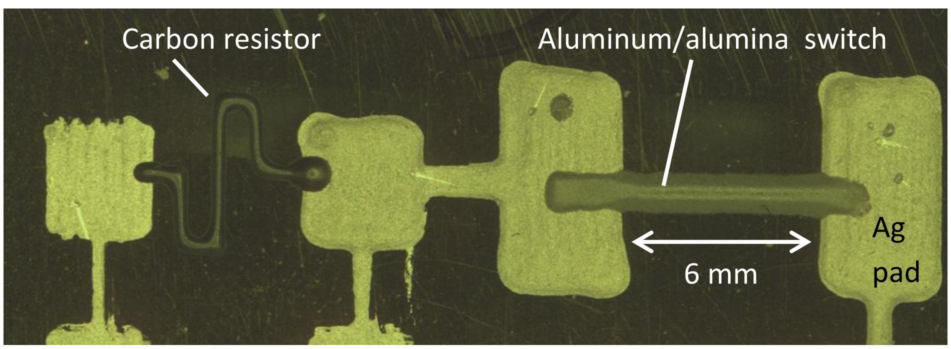

Figure 1. Switching circuit elements formed by direct ink writing

Particles were tested in a circuit configuration shown in Figure2. Voltage and current were measured simultaneously as the switch potential was increased to up to 2000 V. To obtain a switching threshold of greater than 1000 V, these 10-14 micron alumina-coated aluminum particles were written to span 6 mm gap between electrodes.

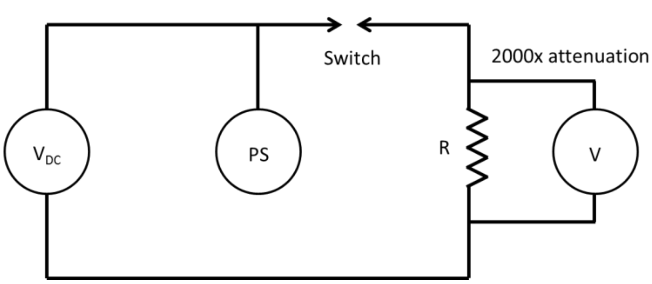

Figure 2. Electrical test configuration; PS is the power supply. For the case of the ALD switch circuits the series resistance R is provided by a carbon-based serpentine.

Switching current characteristics for a 5 mm long ALD particle switch and a 1 mm long air gap switch are shown in Figure 3 (to greater than 3 microseconds) and Figure 4 (less than one microsecond). Switching times are comparable for the two devices, though switching currents are reduced by about a factor of five for the ALD switch relative to the air gap switch. The series resistances were comparable for these two circuits: 10 kohm for the air gap switch, and 13.6 kohm for the ALD particle switch.

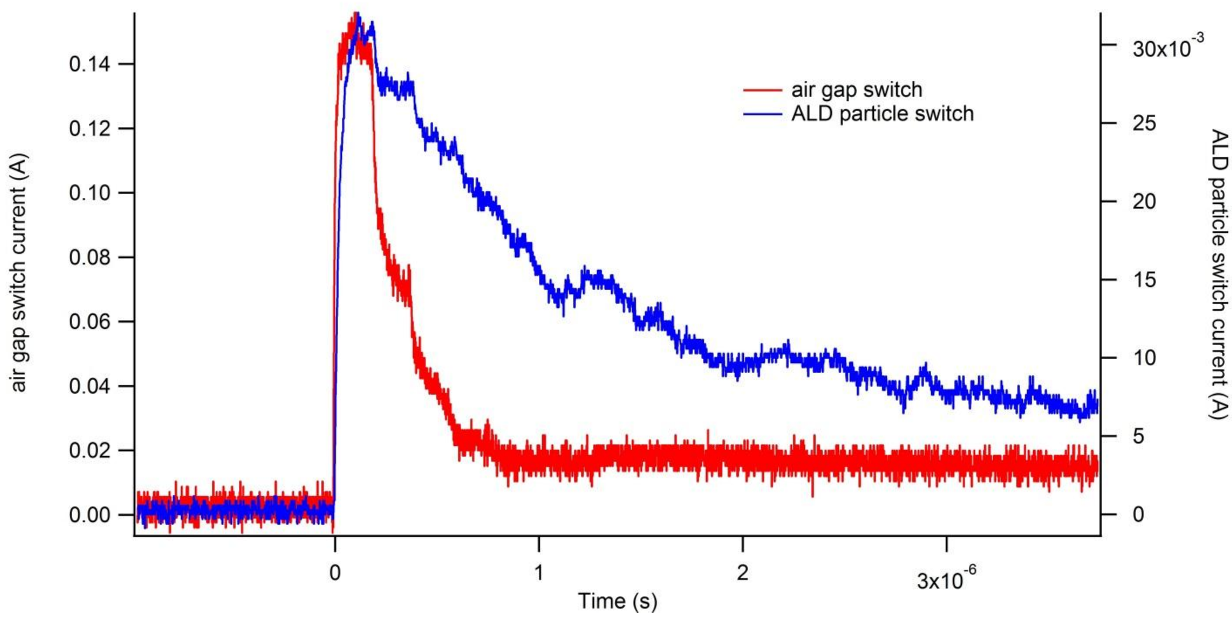

Figure 3. Comparison of the ALD particle switch with an air gap switch.

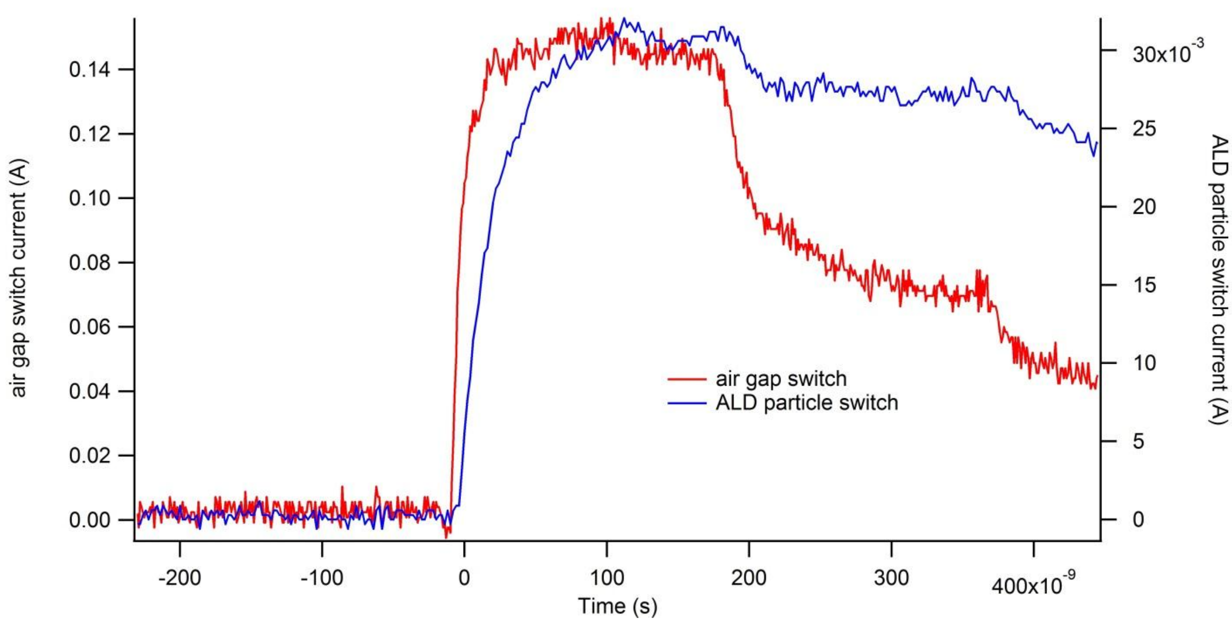

Figure 4. Switch comparison at times less than a microsecond.

In the case of the ALD particle switch, the current rate of rise is 7.6×10^{5} A/s over the initial 30 ns. In the case of the air gap switch, by contrast, the rate of rise is 9×10^{6} A/s over 10 ns.

This type of switch may find utility when integrated into structures that are made of polymers or other low temperature materials, and when the switch is used in environments where changes of air pressure or humidity may preclude use of air gap switches. The multiple control parameters (particle size, composition, switch geometry) for switching voltage threshold allow tuning of this threshold parameter over a wide dynamic range.

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